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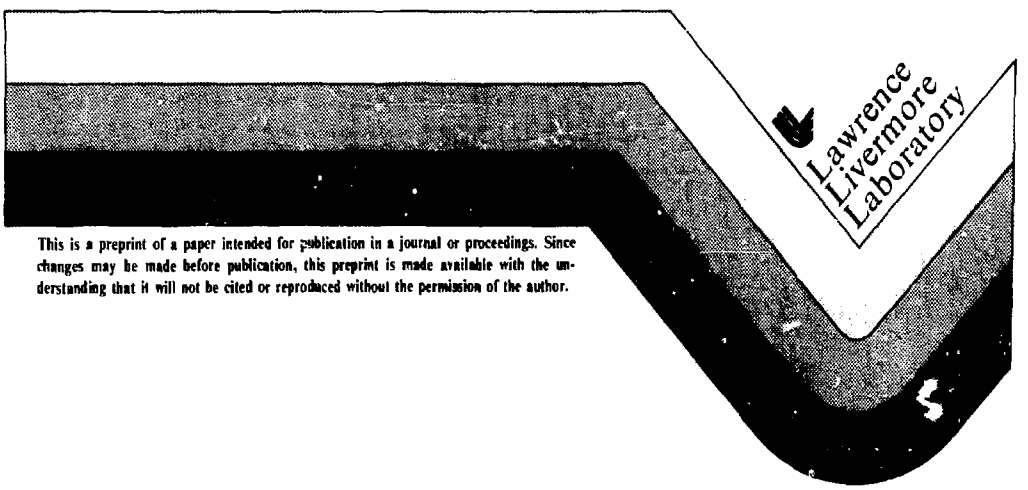

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ABSTRACT

Advanced target designs require thicker ($\sim$300 μm) coatings and better surface finishes than can be produced with current coating techniques. An advanced coating technique is proposed to provide maximum control of the coating flux and optimum manipulation of the shell during processing. In this scheme a small beam of ions or particles of known incident energy are collided with a levitated spherical mandrel. Precise control of the incident energy and angle of the deposition flux optimizes the control of the coating morphology while controlled rotation and noncontact support of the shell minimizes the possibility of particulate or damage generated defects. Almost infinite variability of the incident energy and material in this process provides increased flexibility of the target designs which can be physically realized.

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INTRODUCTION

Coating laser fusion targets requires a process which can provide a high surface finish and which can deposit relatively thick layers of a wide range of materials -- both metals and organics. The processes to date that produce high surface finish coatings are typified by low target yield and dependence on complex physical processes which are poorly understood in their relationship with coating results. Examples of the processes are plasma polymerization[1] and sputtering.[2] Charged particle beam coating is a relatively new technique which may provide a highly controllable flux of coating material. In what follows we will more clearly state the target coating problems, consider the desired effects of an ideal coating flux and target coating system, and present charged particle coaters as a possible improvement in target coating technology.

Fusion Target Coatings

Current target designs include severe constraints on such items as: atomic density and number, material and geometric uniformity and surface finish. The density and atomic number requirements are determined by equation of state calculations used in modeling the physics of the implosion. The surface finish is dictated by the Ragleigh-Taylor criterion for a stable implosion and is shown in Figure 1 for a current target and a reactor class target. These surface finish requirements are only met with coatings of amorphous materials. Even polycrystalline

materials with grain sizes of a fraction of a micron will result in unsatisfactory surface finishes after coating to thicknesses of tens of microns due to crystalline facet defects enhanced by the geometric shadowing process.

There are four basic types of target coatings: ablators, pushers, preheat shields, and diagnostic layers. Ablators tend to be thick (~100 μm), low Z, low density materials. Pushers are thin (~10 μm), high density, high Z materials. Preheat shields are low Z materials of modest thickness (~10-35 μm), seeded with atomically dispersed high Z materials. Diagnostic layers can be of a wide range of materials, some perhaps isotopically pure, radioactive, or as simple as normal copper. The layers of diagnostic material are placed in the target to undergo some neutron activation during the implosion.[3]

In addition to coating requirements, there are constraints on the substrate, itself. Currently, substrates are thin, glass microshells filled with several tens of atmospheres of D-T. These glass microshells must be kept below 100°C during the coating process in order that they will retain their D-T fuel. Future, metal shell substrates may have similar temperature limitations due to diffusion of the fuel or hydrogen embrittlement. Contamination is another substrate problem, both prior to and during the coating process. Particulate contamination, which nucleates defects in the coating, may be minimized by levitating the substrate.[4]

Figure 2 shows a target consisting of an inner, D-T filled shell nested within an ablator shell with a void region between the inner and outer shells.[5] Target performance is enhanced if this ablator is made seamless by coating most of the ablator onto a thin sphere assembled from two hemishells. This assembly substrate is fragile and requires gentle levitation to insure against damage during coating.

Based on coating and substrate requirements, one can conceptually design an ideal coating system. Such a system should be capable of supporting a variety of different target substrates in a contact-free, high vacuum, low temperature environment. A coating flux of any desired material (organic, inorganic, low-Z, high-Z, isotopically pure, etc.) should be available. The coating flux must produce smooth, amorphous coatings at realistic coating rates (several μm/hr.). Such a coating flux might be in the form of one or several beams focused onto the ball, providing nearly normal incidence of coating particles. Fine control of the energy of the incident flux is necessary to insure that the coatings grow as an amorphous structure.[2] Finally, it may be desirable to coat many different layers on a single substrate, or, compound, single layers (alloying or seeding) which are critically tailored to design specifications.

The components for an ideal vacuum coating system, either currently exist, or are in the development stage. Contact free support and manipulation of target substrates can be accomplished by electrostatic

levitation techniques.[6] Particle beam coating, which is in an incipient stage, will be discussed in the remainder of this paper.

Charged Particle Coaters

The first scheme to be considered for charged particle coating provides the coating flux as ions. The ions are focused on to a spherical substrate suspended in a quadrupole levitator as shown in Figure 3. The quadrupole levitation system can inject, extract, and charge delicate assemblies or shells, and is capable of electrically damping the motion of a shell by optically sensed position feedback control. Rotation can be provided by orogrammable electrostatic potentials applied to the levitation electrodes.

The beam of ions is focused onto the center of the substrate allowing normal incidence of the coating flux on the shell. The shell is charged to a potential which slows an ion beam of energy (5-25 keV) to the arrival energy (10-100 eV). The substrate serves as the final element of the deccelerating lens to focus the coating flux onto the surface. The potential of the shell is regulated by an electron beam focused onto the target. This target potential is controlled to produce the desired arrival energy for the incident coating flux.

The proposed coating technique allows material flexibility even to isotopic levels[7], normal incidence of the coating flux, high vacuum processing, coating limited extensively to the shell, and control of arrival energy of the adatom flux.

The eventual utility of this method depends on the answers to two major questions concerning the coating rates. The coating rate for adatoms arriving at a radiation cooled target is given by:

$$R_C\ (\mu m/hr.) = \frac{2.25 \times 10^{19}\ At.W.\ \sigma\ \varepsilon\ (T_B^4 - T_C^4)}{\rho\ W\ (eV)\quad N_a}$$

where σ is the Stefen-Boltzman constant, ε the emissivity, At.W. the atomic weight, ρ the density, N_a Avogadro's number, and T_B and T_C the absolute temperature of the shell and the chamber respectively. Assuming gold and the following values:

$$\varepsilon = 0.1$$

$$\rho = 19.3\ g/cc$$

$$W = 30\ eV$$

we compute the values found in Table 1. For any chamber temperature, even cryogenic, and when the substrate temperature is limited to the level where amorphous coatings result,[2] the coating rate is limited to a few microns per hour.

The assumption was that 30 eV/atom was needed to produce full density material with a cold substrate. Experiments with ion beam deposited materials,[8,9,10,11] except for a few instances, have been conducted with arrival energies greater than 100 eV. A magnesium coating at 24 eV incident energy was grown to 0.2 μm thick by J. Amano et al[9] and found

to have a "corrugated surface with pebble like protrusions". Whether these are due to substrate defects or some material order is inconclusive from his data. Altering the material properties through alloying, to enhance amorphous tendencies, should allow full density materials to be deposited at lower incident energies. Such material improvements are critical for improving the coating rate and establishing this method.

A second, but not minor consideration, is the space charge problem of focusing low energy, relatively high current density beams on targets. Consider a beam that can only coat a spherical mandrel within 20^0 of normal incidence. Each beam illuminates 6% of the sphere surface with coating flux at any one time. To coat at 1 μm/hr. requires $\sim$ 1 amp/cm^2 average current on the target surface area. While this is only $\sim$ 0.12 microamperes total current, the space charge is very high at these low energies. For example, the space charge limited distance for propagating an unneutralized, 1 amp/cm^2 beam of gold ions is 3.5 micrometers. Since this is unrealistically close to place a lens electrode, the shell must act as the final element in a focusing, deccelerating lens that delivers the ions to the target. First order calculations show that this lens will perform to these specifications. Higher order calculations, including astigmatism and chromaticity of the lenses, have only been approximated, but indicate that a high brightness source would provide this current at the target. Sources exist with brightnesses of $\sim 10^6$ amps/cm^{2}sr in a variety of ions.[12,13,14,15,16,17] The sources appear capable of providing the coating flux to the target as considered in simple calculations. A detailed calculation that models the complete problem is being developed and will be reported later.

The space charge problem of high coating fluxes combined with the development of ion sources for a wide variety of materials leads us to consider a different coating concept. In this concept, clusters of the coating atoms are formed in a diverging orifice and charged in an electron beam. A relatively wide range of charge-to-mass ratio particles (as compared to ions) are then accelerated to the substrate. This process offers high coating rates (μm/min.) on cooled substrates. In its current state of development, the cluster flux is accompanied by high fluxes of ions and neutrals to the coating surface. Recent experiments by Takagi, et al[18] have shown that coatings formed from clusters are polycrystalline at arrival energies ∿ 1.0 eV/adatom and substrate temperatures ∿ 300°C. He concludes that the clusters disperse on surface impact, but did not observe full density materials. There is insufficient data from any of the experiments with cluster coating to conclude that amorphous, full density materials can be made from clusters.

Several workers in the field have attempted to generate crystalline and metal coatings. Theeten, et al[19] achieved a low density, polycrystalline coating of CdTe with a heated Ga As substrate at 300°C, Ishida et al[20] deposited Au-Be clusters with varying substrate temperature, and Takagi, et al[18] deposited Cu onto glass, Si onto SiO_2, and ZnS onto NaCl. All these experiments produced materials of increasing crystallinity with increasing kinetic energy of the coating cluster flux. The kinetic energy of the clusters was limited to less than 8 kV or ∿ 1 eV/adatom average energy. This limitation occurs

because the flux included ions that sputtered the surface. This situation precluded conclusions about the morphology of surfaces produced by deposition of clusters only.

Development of this coating technique requires extensive cluster source improvement. The source used in our experiments is a 100 μm orifice with partial ionization of the vapor, some of which have formed clusters. This leads to a wide distribution of charge to mass ratio clusters which leads a similar distribution of arrival energy for the coating flux. A second type of source proposed is an extension of electrostatic spraying.[21] This source would provide a similar distribution of material hut could be developed to provide a more uniform size cluster distribution.

Conclusions

If we compare the arrival of sputtered flux, ion beams, and ionized clusters to a substrate, very interesting trends appear. In a coating system there are several ways that energy reaches the substrate. They are:

W_C = heat of condensation

W_R = heat of recombination of ions

W = photon flux

W_n = kinetic energy of neutrals

W_i = kinetic energy of ions

W_e = kinetic energy of electrons

Table 1 shows which physical processes are important in the deposition of energy at the substrate for the three types of coating processes. Sputtering, ion beam coating, and cluster beam coating, respectively, provide increasingly simpler deposition mechanisms. If the technology can be developed, this simplification of the coating process physics will effect more direct and understandable control of the coating flux parameters, and result in much improved target coating technology.

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Figure Captions

1. The wall uniformity requirements for a current target (a) and an advanced target (b) consist of a maximum initial amplitude of the defect vs its lateral dimension. Defects on a coated target can be mapped to defects on the uncoated surface that has been enhanced by geometric shadowing.

2. The double shell target can be constructed with a seamless ablator by assembling thin hemishells about a nested inner shell and coating the hemishell as a unit.

3. Noncontact support for the shell during coating can be provided in a quadropole levitator developed to rotate, inject, extract, and sense the potential on the surface of a levitated target.

Table I

R_C μm or	T_B °K	T_C °K
3.2	473°K	273°K
1.0	373°K	273°K
0.4	323°K	273°K
3.2	473°K	77°K
1.4	373°K	77°K
0.8	323°K	77°K
0.4	273°K	77°K

Table II

Energy Flux Process	Sputtering	Ion Beam Coater	Cluster Beam Coating
Heat of Condensation	x	x	0
Heat of Recombination	x	x	0
Photon Flux	x	0	0
Kinetic energy of ions	x	x	0
Kinetic energy of neutrals	x	0	x
Kinetic energy of electrons	x	0	0

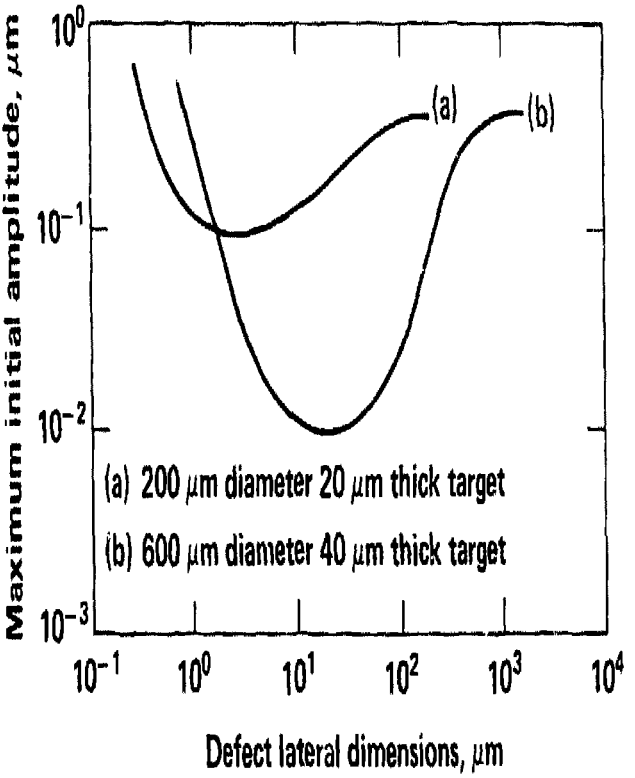
Maximum initial amplitude, μm
10^0
10^-1
10^-2
10^-3
(a)
(b)
(a) 200 μm diameter 20 μm thick target
(b) 600 μm diameter 40 μm thick target
10^-1
10^0
10^1
10^2
10^3
10^4
Defect lateral dimensions, μm

Figure 1

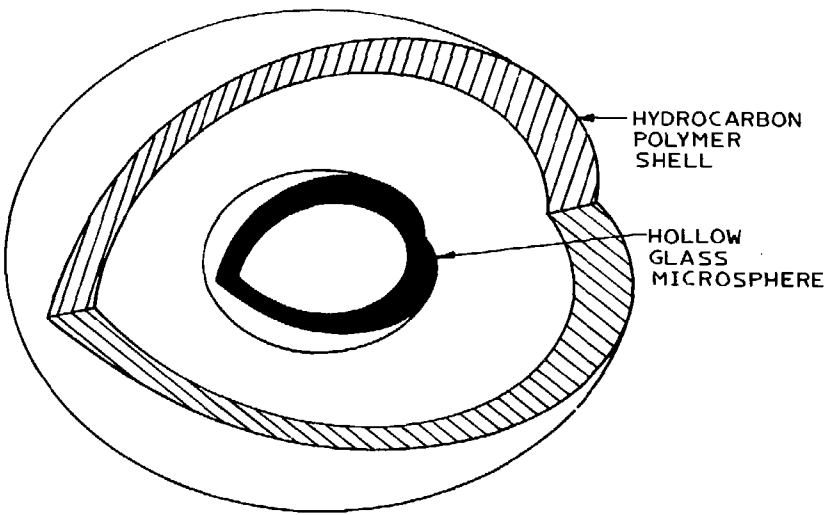

Figure 2

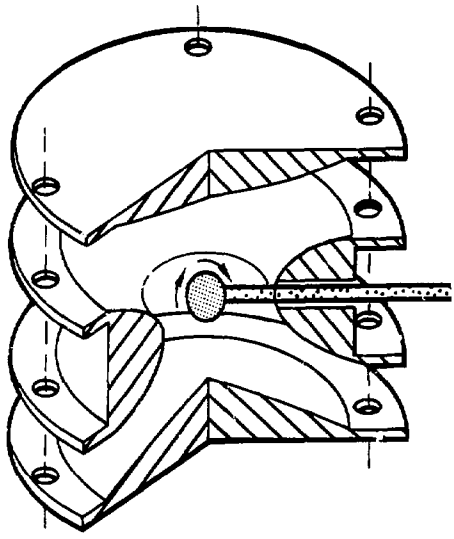

Figure 3